Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project Internal Reference: None

Project: MINERvA

Title: Hole in Vacuum Flange Stress Analysis

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Reviewer(s):

Key Words: MINERvA vacuum flange ISO400 hole stress analysis

Applicable Codes:

Introduction / Abstract

A stress analysis was performed on an ISO400 flange because a hole larger than 50% of its diameter was bored to install a vacuum pump piping assembly. ASME Section VIII does not cover an application when the hole is over 50% unless it is integral to the vessel. Since the flange is not integral to the system, a finite element analysis was done using SolidWorks Simulation.

Description

The ISO400 stainless steel flange is clamped on by 12 or more aluminum double claw clamps. There is a 10.75” hole bored into the center of the flange to accommodate a 10” SCH10S vacuum pipe which runs to the turbo-molecular pump. Pipe is 41” long before it elbows downward and to minimize modeling, it was capped off to mimic the vacuum force.

To determine the clamping force of each clamp, the equation used was (http://www.engineersedge.com/calculators/torque_calc.htm) :

$$F = .2DT$$

Where:
F axial clamping force
D major diameter of fastener
T torque applied to fastener

Assuming a person can finger-tighten to 18 in-lbs (2 N-m) of torque and the major diameter of a M8 bolt is 0.315 inches, then the calculated axial load is 285 lbf which is applied at each of the 12 clamping locations equally-spaced around the edge of the ISO400 flange.

For the purpose of this analysis, the flange was fixed on the seating surface (the centering ring). The inside of the flange face and 10" vacuum piping was placed under full vacuum (-14.7psig). Lastly, 200 lbf was placed at the end of the 41" long vacuum piping to account for the dead load under the elbow such as the pump, extra piping/valving, and the large 8" vacuum gate valve. There is a unistrut support underneath the pipe near the 10" pipe elbow, but it was neglected as a conservative measure.

Analysis

Model Information

DOCUMENT NAME	CONFIGURATION	DOCUMENT PATH	DATE MODIFIED
Flange Assembly	Default	C:\Users\teylix\Documents\Fermilab\MINERvA\Flange Assembly.SLDASM	Fri Jan 21 07:59:03 2011
ISO_400-1	Default	C:\Users\teylix\Documents\Fermilab\MINERvA\ISO_400.SLDPRT	Fri Jan 21 07:59:03 2011

Study Properties

Study name	Study 1
Analysis type	Static

Mesh Type:	Solid Mesh
Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Thermal Effect:	Input Temperature
Zero strain temperature	298.000000
Units	Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Friction:	Off
Ignore clearance for surface contact	Off
Use Adaptive Method:	Off

Units

Unit system:	SI
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	rad/s
Stress/Pressure	N/m^2

Material Properties

NO.	BODY NAME	MATERIAL	MASS	VOLUME
1	SolidBody 1(Boss-Extrude1)	[SW]AISI 304	60.692 kg	0.0075865 m^3

MATERIAL NAME:	[SW]AISI 304
Description:	
Material Source:	
Material Model Type:	Linear Elastic Isotropic
Default Failure Criterion:	Unknown
Application Data:	

PROPERTY NAME	VALUE	UNITS	VALUE TYPE
Elastic modulus	1.9e+011	N/m^2	Constant
Poisson's ratio	0.29	NA	Constant
Shear modulus	7.5e+010	N/m^2	Constant
Mass density	8000	kg/m^3	Constant
Tensile strength	5.1702e+008	N/m^2	Constant
Yield strength	2.0681e+008	N/m^2	Constant
Thermal expansion coefficient	1.8e-005	/Kelvin	Constant
Thermal conductivity	16	W/(m.K)	Constant
Specific heat	500	J/(kg.K)	Constant

Loads and Restraints

Fixture

RESTRAINT NAME	SELECTION SET	DESCRIPTION
Fixed-1 <ISO_400-1>	on 1 Face(s) fixed.	Fixed on seating surface

Load

LOAD NAME	SELECTION SET	LOADING TYPE	DESCRIPTION
Pressure-1 <ISO_400-1>	on 1 Face(s) with Pressure -14.7 psi along direction normal to selected face	Sequential Loading	External pressure on flange
Pressure-2 <ISO_400-1>	on 2 Face(s) with Pressure 14.7 psi along direction normal to selected face	Sequential Loading	External pressure on piping
Force-1 <ISO_400-1>	on 12 Face(s) apply normal force 285 lbf using uniform distribution	Sequential Loading	Clamping force
Force-2 <ISO_400-1>	on 1 Face(s) apply force 200 lbf along plane Dir 2 with respect to selected reference Right Plane using uniform distribution	Sequential Loading	Turbo pump piping load

Mesh Information

Mesh Type:	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off

Smooth Surface:	On
Jacobian Check:	4 Points
Element Size:	0.7837 in
Tolerance:	0.039185 in
Quality:	High
Number of elements:	19592
Number of nodes:	38629
Time to complete mesh(hh;mm;ss):	00:00:10

Reaction Forces

SELECTION SET	UNITS	SUM X	SUM Y	SUM Z	RESULTANT
Entire Body	N	-0.162903	-889.545	-27512.1	27526.5

Free-Body Forces

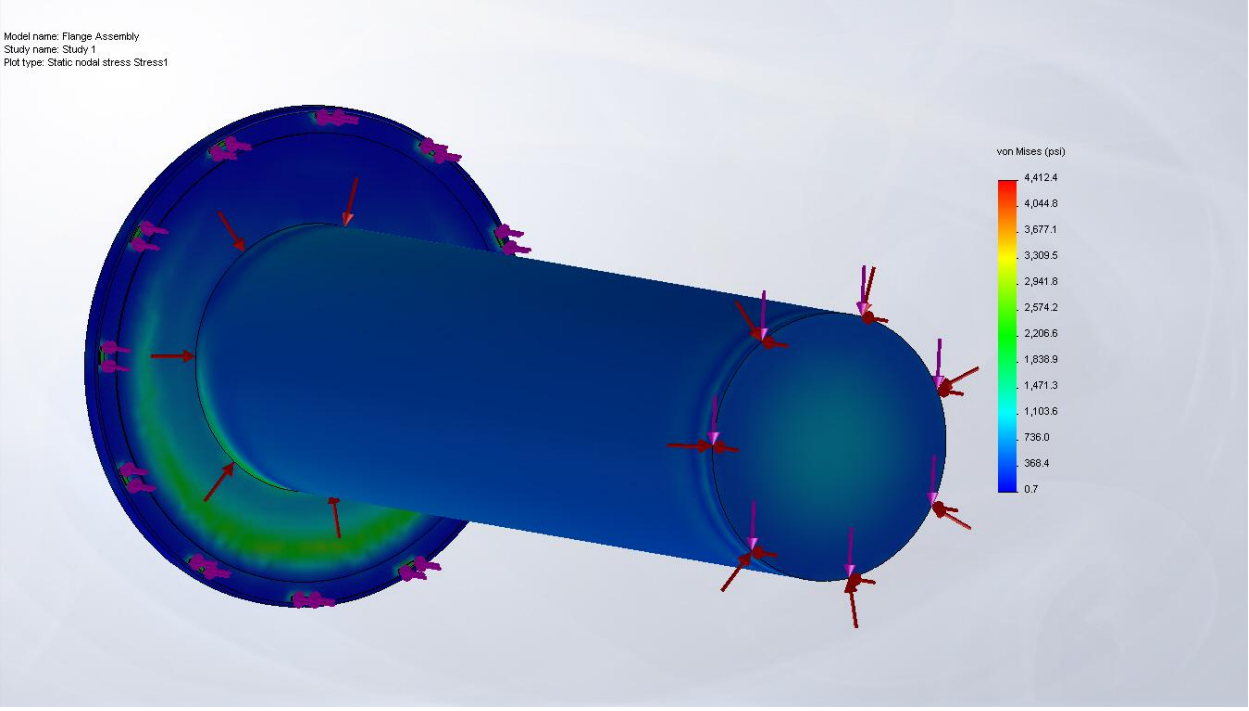
SELECTION SET	UNITS	SUM X	SUM Y	SUM Z	RESULTANT
Entire Body	N	-0.0193509	0.0293461	-0.0218724	0.0414011

Free-body Moments

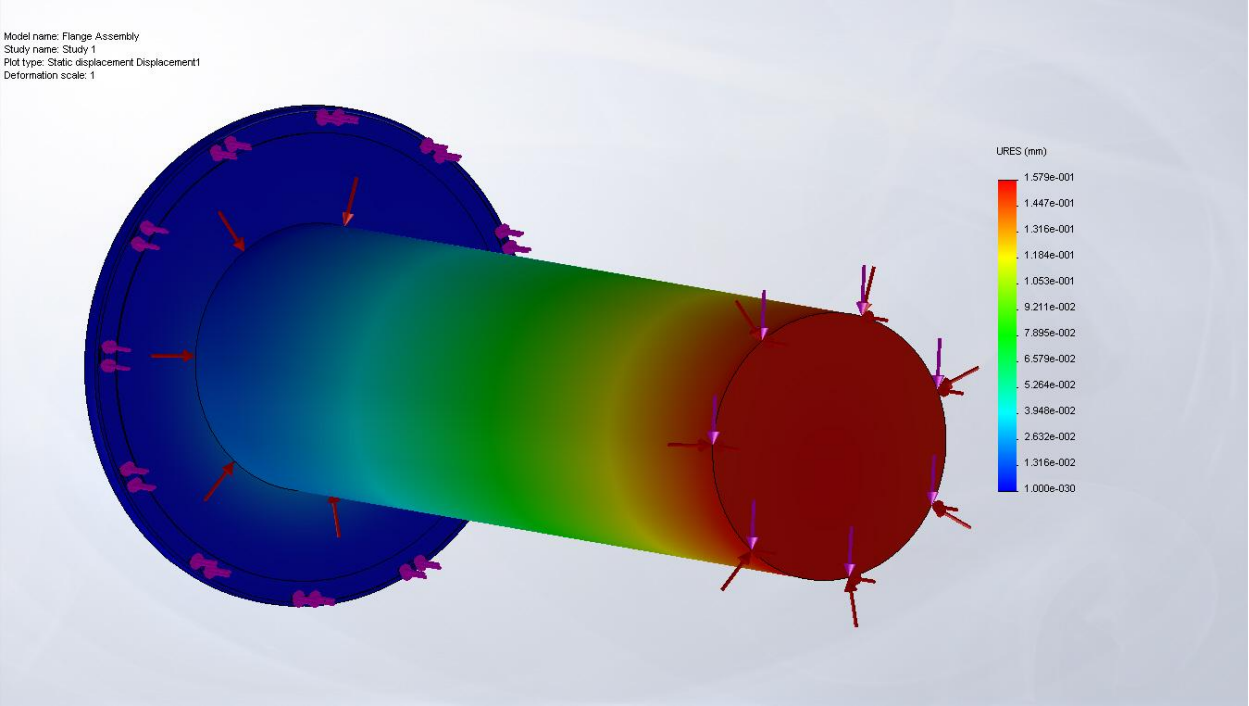
SELECTION SET	UNITS	SUM X	SUM Y	SUM Z	RESULTANT
Entire Body	N-m	0	0	0	1e-033

Study Results

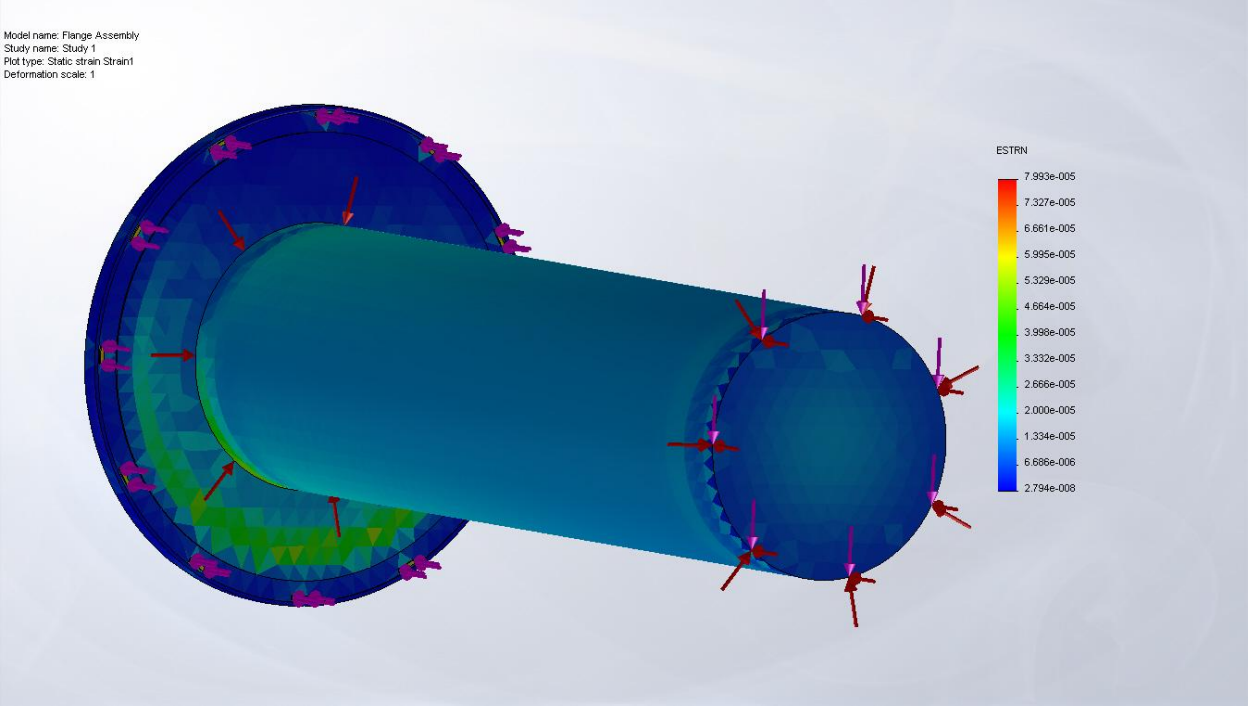
NAME	TYPE	MIN	LOCATION	MAX	LOCATION
Stress1	VON: von Mises Stress	0.709175 psi Node: 15010	(-3.86992 in, -8.5473 in, 0.570398 in)	4412.41 psi Node: 13952	(-1.59406 in, 8.37269 in, 0.393398 in)
Displacement1	URES: Resultant Displacement	0 mm Node: 3466	(9.00387 in, 0.520706 in, 0.570398 in)	0.157906 mm Node: 6866	(-1.15468 in, 1.6914 in, -42.0982 in)
Strain1	ESTRN: Equivalent Strain	2.79448e-008 Element: 608	(-3.57687 in, -8.74651 in, 0.46676 in)	7.99282e-005 Element: 19031	(8.72639 in, 0.614562 in, -0.167208 in)



Flange Assembly-Study 1-Stress-Stress1



Flange Assembly-Study 1-Displacement-Displacement1



Flange Assembly-Study 1-Strain-Strain1

Conclusion

Overall, the analysis ran shows that the system is not heavily stressed. The highest stresses (4412 psi) are actually at the clamping points rather than the flange or piping themselves. Those stresses can be suspect (higher than they would be actually) because in order to model the faces to apply the clamping forces, the faces were raised up off the lid of the flange. Those could be stress risers in the program but since the stresses are still less than half of the allowable, it is not a concern.

Maximum stress in the actual flange (outside of the clamping points) is ~2500 psi which is less than 25% of the allowable of 304L SS. In summary, the flange will be able to accept a 10.75" bored hole while under vacuum and external loading.